Synchrotron X-Ray PEEM study of vortex dynamics in ferromagnetic nanodots

Scientific Achievement

The magnetization distribution in small ferromagnetic particles (dots) depends on their size and shape. For mesoscopic sizes and non-elliptical particle shapes, non-uniform magnetization distributions with zero remanence (“vortex” state) are often observed. These states can be stable within a wide range of dot sizes from a few tens of *nm* up to a few tens of microns. Calculations of the eigenfrequencies of quantized spin excitations in small magnetic elements are complicated due to their non-ellipsoidal shape and non-uniform ground state.

We have explored the spin dynamics in the vortex state and determined the low-lying vortex eigenfrequncies. Direct imaging by means of X-ray photoemission electron microscopy of the dynamics of magnetic vortices confined in micron-sized circular permalloy dots that are 30-nm thick allowed us to explore the eigenfrequencies and eigenmode distributions. The high resolution XMCD/PEEM pump-probe technique was used. The vortex core positions oscillate on a 10-ns timescale in a self-induced magnetostatic potential well after the in-plane magnetic field is turned off. The measured frequencies as a function of the aspect ratio (thickness/radius) of the dots are in agreement with theoretical calculations for the same geometry. The observed vortex core position oscillations are interpreted as the translational mode of the vortex motion around the equilibrium position induced by a gyroforce and a dynamic magnetostatic restoring force. The non-zero gyrovector, an intrinsic property of the vortex arising from non-zero topological charges of the vortex core, is principally important for the vortex dynamics description. Our clear observation of the core oscillations and the eigenfrequency dependence on the dot radius resolved existing contradictions between the experimental results of the SLS and ALS groups.

Significance

Understanding the fundamentals of the magnetization dynamics in systems with reduced dimensionality is central to the future advancement of the field of nanomagnetism. Thus, it becomes important to calculate and observe the eigenfrequencies of sub-micron magnetic elements. The vortex excitations can be used to describe non-uniform reversal modes in magnetic nano-dots (an important problem for patterned, high-density recording media). The development of a new concept of a.c. field driven dynamical magnetization reversal in magnetic dots in vortex ground state is expected to be important to understand dynamical experiments on thin magnetic dots and for magnetic recording applications.

Part of this work has already been published [*Phys Rev. Lett*. **96**, in press (2006)] and conference talk has been presented (50^{th} Conf. Magnetism and Magnetic Materials, Nov. 2005).

Performers

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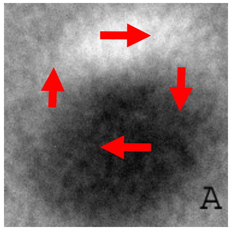
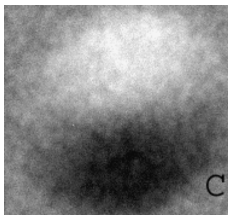
Time resolved Photoemission Electron Microscopy (PEEM) experiment at APS

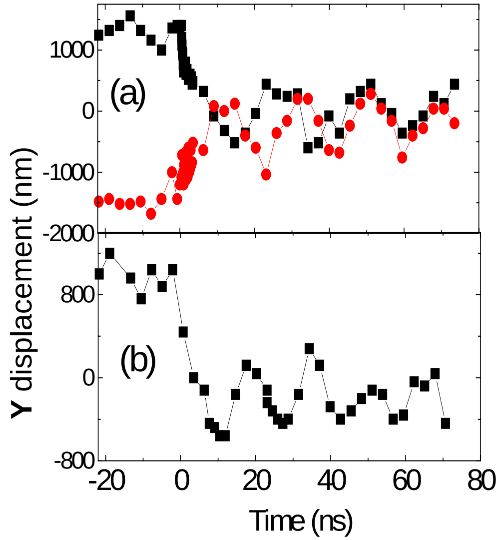
0 ns

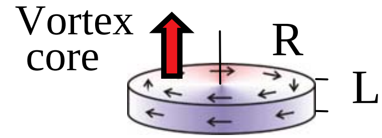


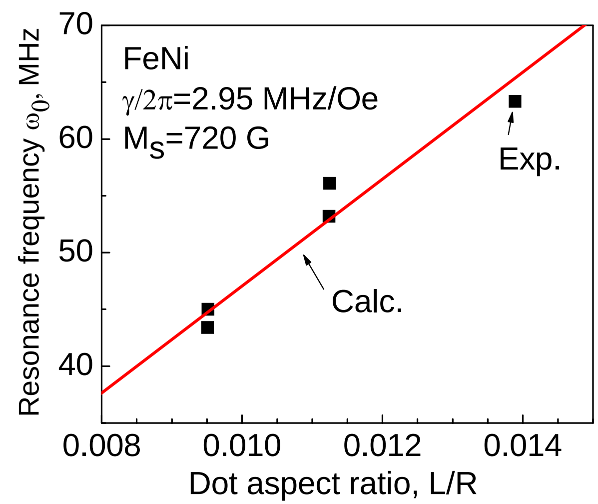
field **H**

14.7 ns









PEEM images of the dot (30-nm thick, 6.3) μm diameter as a function of time

Time dependence of the vortex core position ⊥ **H**:
(a) 6.3-μm diameter dot - black, 5.3-μm dot - red;
(b) 4.3 μm dot

Oscillations in the XMCD/PEEM image of the vortex core position are in agreement with Guslienko's model:

eigenfrequency $\omega_0 = \gamma M_s (20/9) L/R$

Future: **elliptic and tri-layer F/N/F dots, field driven vortex core reversal**

Guslienko et al., *Phys. Rev. Lett.* **96**, (2006)

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